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(54) **Space time block coded transmit antenna diversity for WCDMA**

(57) A mobile communication system is designed with an input circuit coupled to receive a first plurality of signals ($r_j(i+\tau_j)$, i=0-N-1) during a first time (T0-T1) from an external source and coupled to receive a second plurality of signals ($r_j(i+\tau_j)$, i=N-2N-1) during a second time (T1-T2) from the external source. The input circuit receives each of the first and second plurality of signals along respective first and second paths (j). The input circuit produces a first input signal (610) (R_j^1) and a second input signal (614) (R_j^2) from the respective first and second plurality of signals. A correction circuit is coupled to receive a first estimate signal (302) (α_j^1), a second estimate signal (306) (α_j^2) and the first and second input signals. The correction circuit produces a first symbol estimate ($\tilde{S}_1$) in response to the first and second estimate signals and the first and second input signals. The correction circuit produces a second symbol estimate ($\tilde{S}_2$) in response to the first and second estimate signals and the first and second input signals.

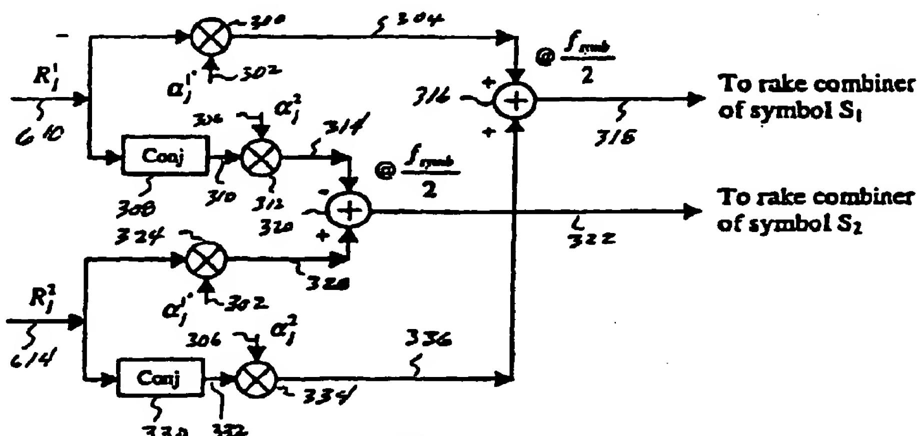

FIG. 3

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Description

FIELD OF THE INVENTION

[0001] This invention relates to wideband code division multiple access (WCDMA) for a communication system and more particularly to space time block coded transmit antenna diversity for WCDMA.

BACKGROUND OF THE INVENTION

[0002] Present code division multiple access (CDMA) systems are characterized by simultaneous transmission of different data signals over a common channel by assigning each signal a unique code. This unique code is matched with a code of a selected receiver to determine the proper recipient of a data signal. These different data signals arrive at the receiver via multiple paths due to ground clutter and unpredictable signal reflection. Additive effects of these multiple data signals at the receiver may result in significant fading or variation in received signal strength. In general, this fading due to multiple data paths may be diminished by spreading the transmitted energy over a wide bandwidth. This wide bandwidth results in greatly reduced fading compared to narrow band transmission modes such as frequency division multiple access (FDMA) or time division multiple access (TDMA).

[0003] New standards are continually emerging for next generation wideband code division multiple access (WCDMA) communication systems as described in European Patent Application No. EP 99201224.5 filed April 21, 1999, and incorporated herein by reference. These WCDMA systems are coherent communications systems with pilot symbol assisted channel estimation schemes. These pilot symbols are transmitted as quadrature phase shift keyed (QPSK) known data in predetermined time frames to any receivers within range. The frames may propagate in a discontinuous transmission (DTX) mode. For voice traffic, transmission of user data occurs when the user speaks, but no data symbol transmission occurs when the user is silent. Similarly for packet data, the user data may be transmitted only when packets are ready to be sent. The frames include pilot symbols as well as other control symbols such as transmit power control (TPC) symbols and rate information (RI) symbols. These control symbols include multiple bits otherwise known as chips to distinguish them from data bits. The chip transmission time (T_C), therefore, is equal to the symbol time rate (T) divided by the number of chips in the symbol (N).

[0004] Previous studies have shown that multiple transmit antennas may improve reception by increasing transmit diversity for narrow band communication systems. In their paper New Detection Schemes for Transmit Diversity with no Channel Estimation, Tarokh et al. describe such a transmit diversity scheme for a TDMA system. The same concept is described in A Simple Transmitter Diversity Technique for Wireless Communications by Alamouti. Tarokh et al. and Alamouti, however, fail to teach such a transmit diversity scheme for a WCDMA communication system.

[0005] Other studies have investigated open loop transmit diversity schemes such as orthogonal transmit diversity (OTD) and time switched time diversity (TSTD) for WCDMA systems. Both OTD and TSTD systems have similar performance. Both use multiple transmit antennas to provide some diversity against fading, particularly at low Doppler rates and when there are insufficient paths for the rake receiver. Both OTD and TSTD systems, however, fail to exploit the extra path diversity that is possible for open loop systems. For example, the OTD encoder circuit of FIG. 5 receives symbols S_1 and S_2 on lead 500 and produces output signals on leads 504 and 506 for transmission by first and second antennas, respectively. These transmitted signals are received by a despreader input circuit (FIG. 6). The input circuit receives the i^{th} of N chip signals per symbol together with noise along the j^{th} of L multiple signal paths at a time τ_j after transmission. Both here and in the following text, noise terms are omitted for simplicity. This received signal $r_j(i+\tau_j)$ at lead 600 is multiplied by a channel orthogonal code signal $C_m(i+\tau_j)$ that is unique to the receiver at lead 604. Each chip signal is summed over a respective symbol time by circuit 608 and produced as first and second output signals R_j^1 and R_j^2 on leads 612 and 614 as in equations [1-2], respectively. Delay circuit 610 provides a one-symbol delay T so that the output signals are produced simultaneously.

$$R_j^1=\sum_{i=0}^{N-1} r_j(i+\tau_j)=\alpha_j^1 S_1+\alpha_j^2 S_2 \qquad [1]$$

$$R_j^2=\sum_{i=N}^{2N-1} r_j(i+\tau_j)=\alpha_j^1 S_1-\alpha_j^2 S_2 \qquad [2]$$

[0006] The OTD phase correction circuit of FIG. 7 receives the signals R_j^1 and R_j^2 as input signals corresponding to the j^{th} of L multiple signal paths. The phase correction circuit produces soft outputs or signal estimates $\tilde{S}_1$ and $\tilde{S}_2$ for symbols S_1 and S_2 at leads 716 and 718 as shown in equations [3-4], respectively.

$$\tilde{S}_1=\sum_{j=1}^{L}(R_j^1+R_j^2)\alpha_j^{1*}=\sum_{j=1}^{L}2|\alpha_j^1|^2 S_1 \qquad [3]$$

$$\tilde{S}_2=\sum_{j=1}^{L}(R_j^1-R_j^2)\alpha_j^{2*}=\sum_{j=1}^{L}2|\alpha_j^2|^2 S_2 \qquad [4]$$

Equations [3-4] show that the QTD method provides a

single channel estimate α for each path j. A similar analysis for the TSTD system yields the same result. The OTD and TSTD methods, therefore, are limited to a path diversity of L. This path diversity limitation fails to exploit the extra path diversity that is possible for open loop systems as will be explained in detail.

SUMMARY OF THE INVENTION

[0007] These problems are resolved by a mobile communication system comprising an input circuit coupled to receive a first plurality of signals during a first time from an external source and coupled to receive a second plurality of signals during a second time from the external source. The input circuit receives each of the first and second plurality of signals along respective first and second paths. The input circuit produces a first input signal and a second input signal from the respective first and second plurality of signals. A correction circuit is coupled to receive a first estimate signal, a second estimate signal and the first and second input signals. The correction circuit produces a first symbol estimate in response to the first and second estimate signals and the first and second input signals. The correction circuit produces a second symbol estimate in response to the first and second estimate signals and the first and second input signals.

[0008] The present invention improves reception by providing at least $2L$ diversity over time and space. No additional transmit power or bandwidth is required. Power is balanced across multiple antennas.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] A more complete understanding of the invention may be gained by reading the subsequent detailed description with reference to the drawings wherein:

FIG. 1 is a simplified block diagram of a typical transmitter using Space Time Transit Diversity (STTD) of the present invention;
FIG. 2 is a block diagram showing signal flow in an STTD encoder of the present invention that may be used with the transmitter of FIG. 1;
FIG. 3 is a schematic diagram of a phase correction circuit of the present invention that may be used with a receiver;
FIG. 4A is a simulation showing STTD performance compared to Time Switched Time Diversity (TSTD) for a vehicular rate of 3 kmph;
FIG. 4B is a simulation showing STTD performance compared to TSTD for a vehicular rate of 120 kmph;
FIG. 5 is a block diagram showing signal flow in an OTD encoder of the prior art;
FIG. 6 is a block diagram of a despreader input circuit of the prior art; and
FIG. 7 is a schematic diagram of a phase correction circuit of the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] Referring to FIG. 1, there is a simplified block diagram of a typical transmitter using Space Time Transit Diversity (STTD) of the present invention. The transmitter circuit receives pilot symbols, TPC symbols, RI symbols and data symbols on leads 100, 102, 104 and 106, respectively. Each of the symbols is encoded by a respective STTD encoder as will be explained in detail. Each STTD encoder produces two output signals that are applied to multiplex circuit 120. The multiplex circuit 120 produces each encoded symbol in a respective symbol time of a frame. Thus, a serial sequence of symbols in each frame is simultaneously applied to each respective multiplier circuit 124 and 126. A channel orthogonal code C_m is multiplied by each symbol to provide a unique signal for a designated receiver. The STTD encoded frames are then applied to antennas 128 and 130 for transmission.

[0011] Turning now to FIG. 2, there is a block diagram showing signal flow in an STTD encoder of the present invention that may be used with the transmitter of FIG. 1. The STTD encoder receives symbol S_1 at symbol time T and symbol S_2 at symbol time $2T$ on lead 200. The STTD encoder produces symbol S_1 on lead 204 and symbol $-S_2^*$ on lead 206 at symbol time T, where the asterisk indicates a complex conjugate operation. Furthermore, the symbol time indicates a relative position within a transmit frame and not an absolute time. The STTD encoder then produces symbol S_1 on lead 204 and symbol S_1^* on lead 206 at symbol time $2T$. The bit or chip signals of these symbols are transmitted serially along respective paths 208 and 210. Rayleigh fading parameters are determined from channel estimates of pilot symbols transmitted from respective antennas at leads 204 and 208. For simplicity of analysis, a Rayleigh fading parameter α_j^1 is assumed for a signal transmitted from the first antenna 204 along the j^{th} path. Likewise, a Rayleigh fading parameter α_j^2 is assumed for a signal transmitted from the second antenna 206 along the j^{th} path. Each i^{th} chip or bit signal $r_j(i+\tau_j)$of a respective symbol is subsequently received at a remote mobile antenna 212 after a transmit time τ_j corresponding to the j^{th} path. The signals propagate to a despreader input circuit (FIG. 6) where they are summed over each respective symbol time to produce output signals R_j^1 and R_j^2 corresponding to the j^{th} of L multiple signal paths as previously described.

[0012] Referring now to FIG. 3, there is a schematic diagram of a phase correction circuit of the present invention that may be used with a remote mobile receiver. This phase correction circuit receives signals R_j^1 and R_j^2 as input signals on leads 610 and 614 as shown in equations [5-6], respectively.

$$R_j^1=\sum_{i=0}^{N-1} r_j(i+\tau_j)=\alpha_j^1 S_1-\alpha_j^2 S_2^* \quad [5]$$

$$R_j^2=\sum_{i=N}^{2N-1} r_j(i+\tau_j)=\alpha_j^1 S_1+\alpha_j^2 S_1^* \quad [6]$$

The phase correction circuit receives a complex conjugate of a channel estimate of a Rayleigh fading parameter α_j^{1*} corresponding to the first antenna on lead 302 and a channel estimate of another Rayleigh fading parameter α_j^2 corresponding to the second antenna on lead 306. Complex conjugates of the input signals are produced by circuits 308 and 330 at leads 310 and 322, respectively. These input signals and their complex conjugates are multiplied by Rayleigh fading parameter estimate signals and summed as indicated to produce path-specific first and second symbol estimates at respective output leads 318 and 322 as in equations [7-8].

$$R_j^1\alpha_j^{1*}+R_j^{2*}\alpha_j^2=(|\alpha_j^1|^2+|\alpha_j^2|^2)S_1 \quad [7]$$

$$-R_j^{1*}\alpha_j^2+R_j^2\alpha_j^{1*}=(|\alpha_j^1|^2+|\alpha_j^2|^2)S_2 \quad [8]$$

These path-specific symbol estimates are then applied to a rake combiner circuit to sum individual path-specific symbol estimates, thereby providing net soft symbols as in equations [9-10].

$$\tilde{S}_1=\sum_{j=1}^{L} R_j^1\alpha_j^{1*}+R_j^{2*}\alpha_j^2 \quad [9]$$

$$\tilde{S}_2=\sum_{j=1}^{L} -R_j^{1*}\alpha_j^2+R_j^2\alpha_j^{1*} \quad [10]$$

These soft symbols or estimates provide a path diversity L and a transmit diversity 2. Thus, the total diversity of the STTD system is $2L$. This increased diversity is highly advantageous in providing a reduced bit error rate. The simulation result of FIG. 4 compares a bit error rate (BER) of STTD with TSTD for various ratios of energy per bit (Eb) to noise (No) at a relative speed of 3 Kmph. The OTD and TSTD systems were found to be the same in other simulations. The simulation shows that a 7.5 dB ratio Eb/No corresponds to a BER of 2.0E-3 for TSTD. The same BER, however, is achieved with a 7.2 dB ratio Eb/No. Thus, STTD produces approximately 0.3 dB improvement over TSTD. The simulation of FIG. 5 compares the BER of STTD with TSTD for various values of Eb/No at a relative speed of 120 Kmph. This simulation shows a typical 0.25 dB improvement for STTD over TSTD even for high Doppler rates. By way of comparison, STTD demonstrates a 1.0 dB advantage over the simulated curve of FIG. 5 without diversity at a BER of 2.6E-3. This substantial advantage further demonstrates the effectiveness of the present invention.

[0013] Although the invention has been described in detail with reference to its preferred embodiment, it is to be understood that this description is by way of example only and is not to be construed in a limiting sense. For example, several variations in the order of symbol transmission would provide the same *2L* diversity. Moreover, the exemplary diversity of the present invention may be increased with a greater number of transmit or receive antennas. Furthermore, novel concepts of the present invention are not limited to exemplary circuitry, but may also be realized by digital signal processing as will be appreciated by those of ordinary skill in the art with access to the instant specification.

[0014] It is to be further understood that numerous changes in the details of the embodiments of the invention will be apparent to persons of ordinary skill in the art having reference to this description. It is contemplated that such changes and additional embodiments are within the spirit and true scope of the invention.

Claims

1. Circuitry, comprising:

a correction circuit for receiving first and second input signals from an external source along a signal path of a plurality of signal paths, the correction circuit arranged for producing a first symbol estimate in response to first and second estimate signals and the first and second input signals, and for producing a second symbol estimate in response to the first and second estimate signals and the first and second input signals; and

a combining circuit coupled for receiving a plurality of first symbol estimates including the first symbol estimate and for receiving a plurality of second symbol estimates including the second symbol estimate, the combining circuit arranged for producing a first symbol signal in response to the plurality of first symbol estimates and for producing a second symbol signal in response to the plurality of second symbol estimates.

2. A circuitry as in claim 1 further comprising:

an input circuit arranged for receiving a first plurality of signals during a first period from the external source and for receiving a second plurality of signals during a second period from the external source, the input circuit arranged for receiving each of the first and second plurality of signals along respective first and second

paths, the input circuit arranged for producing the first input signal and the second input signal from the respective first and second plurality of signals.

3. A circuitry as in claim 1 further comprising:

an input circuit arranged for receiving a plurality of signals from an external source along a plurality of signal paths, for producing a plurality of input signals including the first input signal and the second input signal corresponding to a respective signal path of the plurality of signal paths.

4. A circuitry as in any preceding claim, wherein the correction circuit and the combining circuit are formed on a single integrated circuit.

5. A circuitry as in any preceding claim, wherein each of the first and second symbol signals includes at least one of a pilot symbol, a transmit power control symbol, a rate information symbol and a data symbol.

6. A circuit as in any preceding claim, wherein the first period corresponds to a transmission time of one of the first and second symbol signals and the second period corresponds to a transmission time of the other of the first and second symbol signals.

7. A circuit as in any preceding claim, wherein a total path diversity of each of the first and second symbol signals is at least twice a number of transmitting antennas.

8. A circuit as in any preceding claim, wherein the first input signal is transmitted by a first antenna and a second antenna and wherein the second input signal is transmitted by the first antenna and the second antenna.

9. A circuit as in claim 8, wherein the first and the second input signal are wideband code division multiple access signals.

10. A method of processing signals in a communication circuit, comprising:

receiving a plurality of first signals during a first period, each first signal corresponding to a respective signal path;
receiving a plurality of second signals during a second period;
estimating a first Rayleigh fading parameter;
estimating a second Rayleigh fading parameter;
producing a first symbol signal in response to said plurality of first signals, said plurality of second signals and said first and second Rayleigh fading parameters; and
producing a second symbol signal in response to said plurality of first signals, said plurality of second signals and said first and second Rayleigh fading parameters.

11. A method of processing signals as in claim 10, further comprising the steps of:

determining a conjugate of said each first signal;
determining a conjugate of each second signal of said plurality of second signals;
determining a conjugate of each said first Rayleigh fading parameter; and
determining a conjugate of each said second Rayleigh fading parameter.

12. A method of processing signals as in claim 11, further comprising the steps of:

determining an approximate said first symbol by adding a product of said each first signal and each respective said conjugate of each said first Rayleigh fading parameter to a product of said conjugate of said each second signal and each respective said second Rayleigh fading parameter; and
determining an approximate said second symbol by adding a product of a complement of said conjugate of said each first signal and each respective second Rayleigh fading parameter to a product of said each second signal and each respective said conjugate of each said second Rayleigh fading parameter.

13. A mobile communication system, comprising:

a mobile antenna arranged for receiving a plurality of signals from an external source along a plurality of signal paths;
an input circuit arranged for receiving the plurality of signals from the antenna, and for producing a plurality of input signals including a first input signal and a second input signal corresponding to respective signal paths of the plurality of signal paths; and
a correction circuit arranged for receiving a first estimate signal, a second estimate signal and the first and second input signals, for producing a first symbol estimate in response to the first and second estimate signals and the first and second input signals, the correction circuit arranged for producing a second symbol estimate in response to the first and second estimate signals and the first and second input

signals.

14. A mobile communication system as in claim 13, further comprising a combining circuit arranged for receiving a plurality of first symbol estimates including the first symbol estimate, and for receiving a plurality of second symbol estimates including the second symbol estimate, the combining circuit arranged for producing a first symbol signal in response to the plurality of first symbol estimates and producing a second symbol signal in response to the plurality of second symbol estimates.

15. A mobile communication system as in claim 14, wherein the input circuit, the correction circuit and the combining circuit are formed on a single integrated circuit.

16. A mobile communication system as in claim 14, wherein each of the first and second symbol signals include at least one of a pilot symbol, a transmit power control symbol, a rate information symbol and a data symbol.

17. A mobile communication system as in any of claims 13 to 16, wherein each of the first and second estimate signals is a Rayleigh fading parameter estimate.

18. A mobile communication system as in any of claims 13 to 17, wherein a total path diversity of each of the first and second symbol signals is at least twice a number of transmitting antennas.

19. A mobile communication system as in any of claims 13 to 18, wherein each of the first and second input signals is transmitted by a first antenna and a second antenna.

20. A mobile communication system as in claim 19, wherein each of the first and second input signals is a wideband code division multiple access signal.

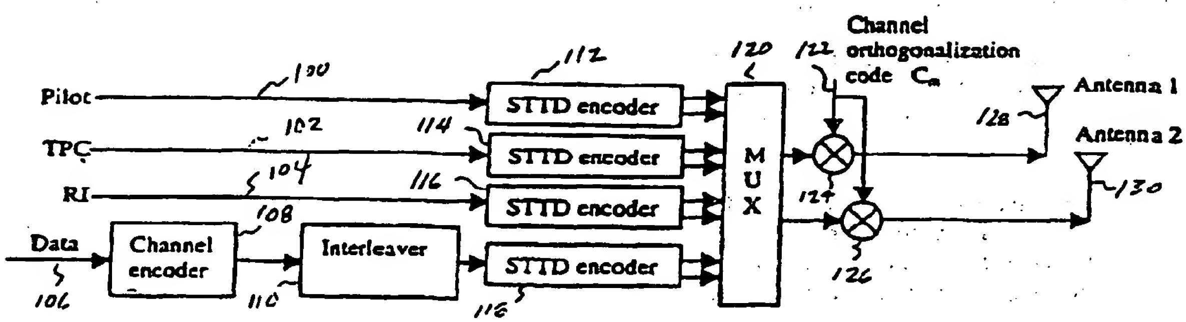

Pilot
TPC
RI
Data
Channel encoder
Interleaver
STTD encoder
STTD encoder
STTD encoder
STTD encoder
M U X
Channel orthogonalization code C_m
Antenna 1
Antenna 2
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
130

FIG. 1

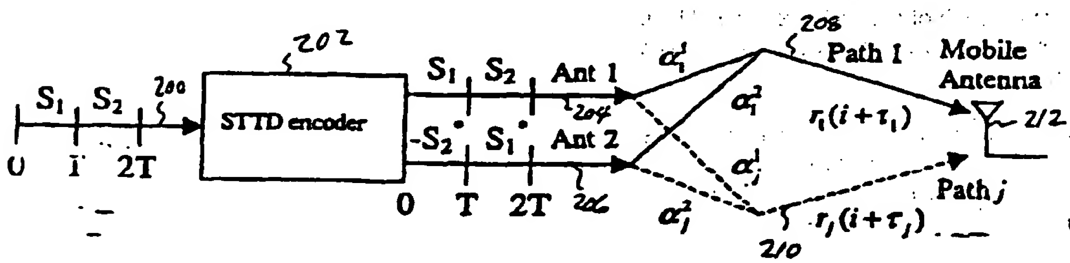
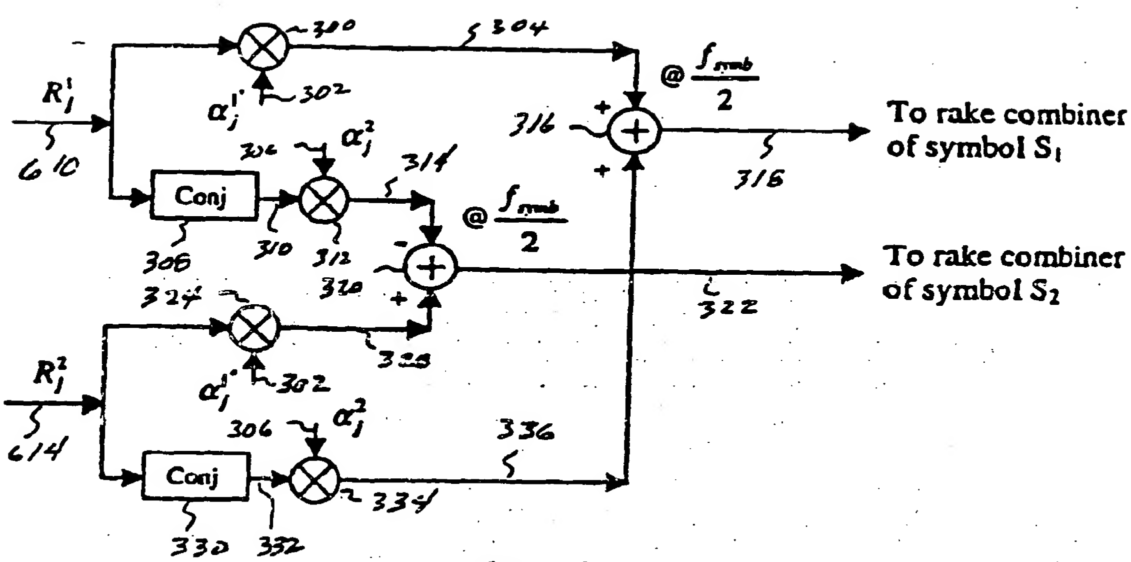
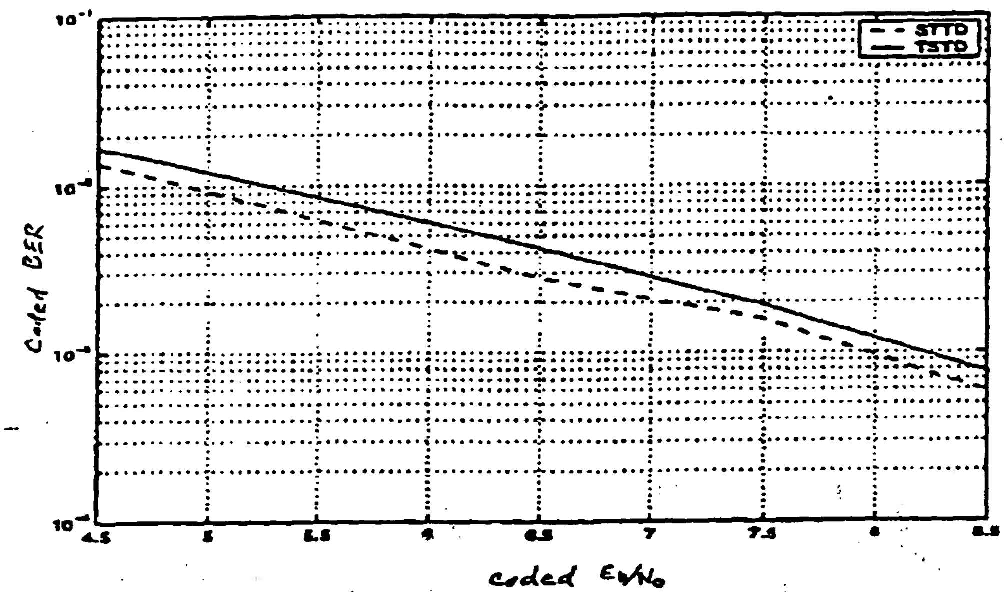

S_1 S_2
0 T 2T
200
202
STTD encoder
S_1 S_2 Ant 1
$-S_2^*$ S_1^* Ant 2
0 T 2T
204
206
α_1^1
α_1^2
α_j^1
α_j^2
208
Path 1
Mobile Antenna
$r_1(i+\tau_1)$
212
Path j
$r_j(i+\tau_j)$
210

FIG. 2



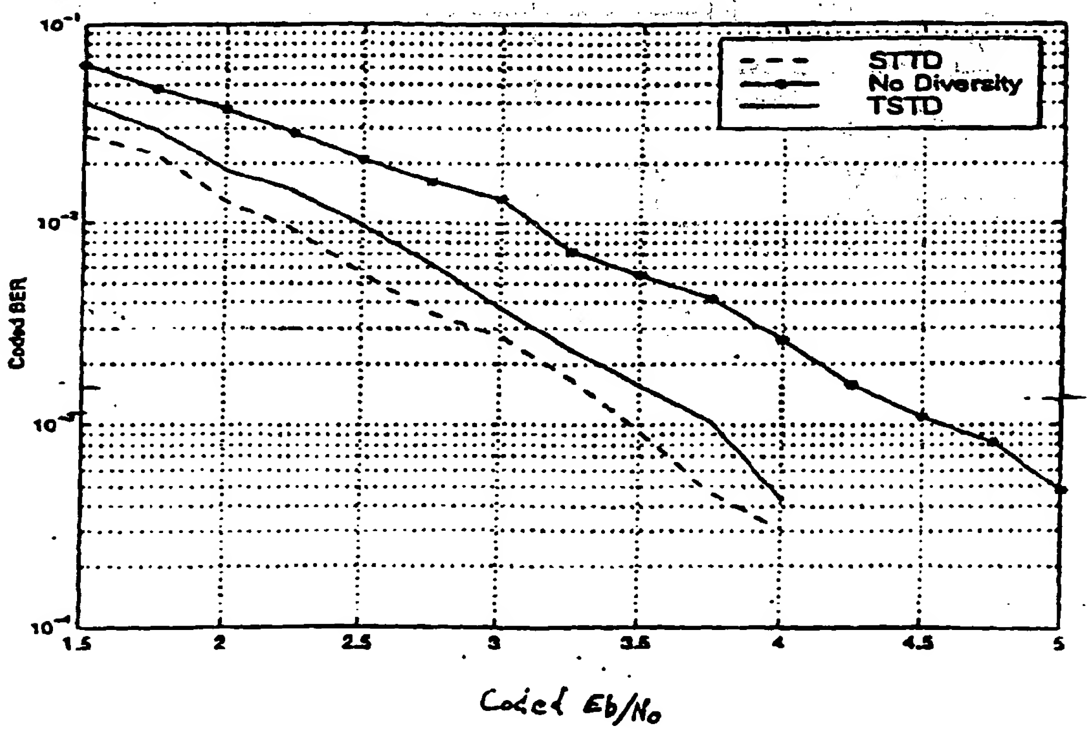
R_j^1
610
300
304
302
α_j^{1*}
306
α_j^2
314
Conj
308
310
312
@ $\frac{f_{symb}}{2}$
316
To rake combiner of symbol S_1
To rake combiner of symbol S_2
320
322
324
328
R_j^2
614
302
α_j^{1*}
306
α_j^2
336
Conj
330
332
334

FIG. 3



STTD
TSTD
Coded BER
coded Eb/No

FIG. 4A



STTD
No Diversity
TSTD
Coded BER
Coded Eb/No

FIG. 4B

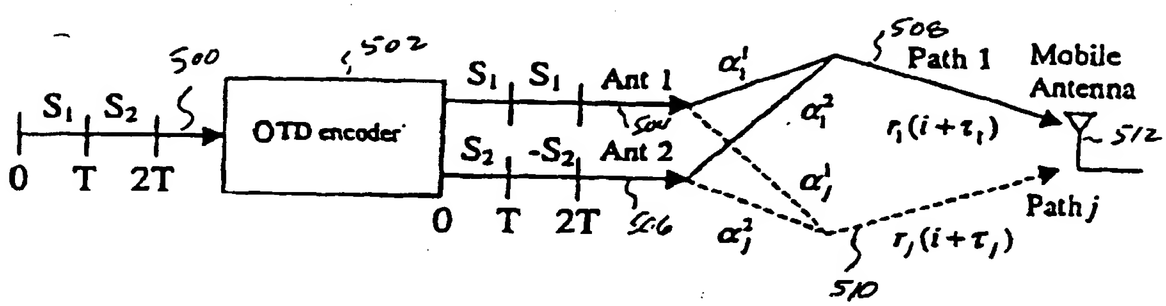


FIG. 5
(PRIOR ART)

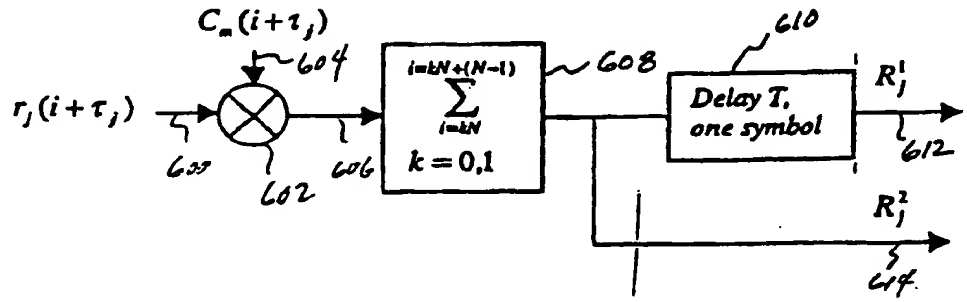


FIG. 6
(PRIOR ART)

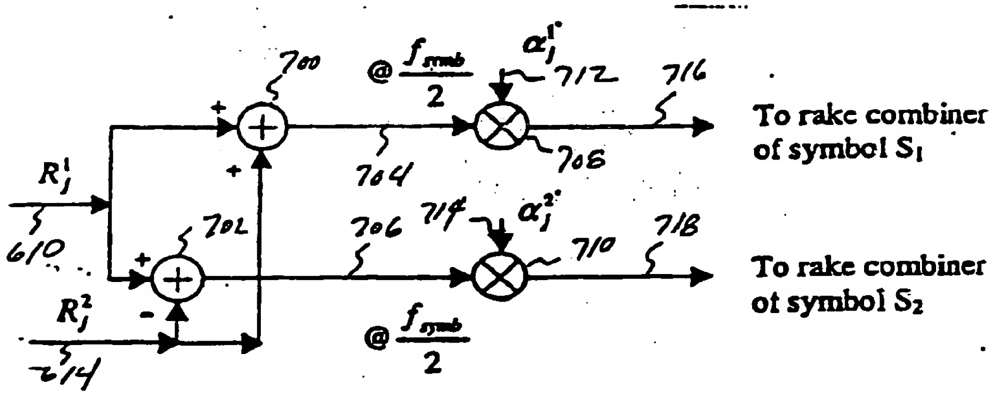


FIG. 7
(PRIOR ART)